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16. ABSTRACT

The performance of two layer asphalt stabilized drainage systems is reported. The two layer drainage system consists of a filter layer of sand-gravel blend filter material, aggregate base or similar material which will satisfy the filter criteria overlain by an open graded drainage layer stabilized with 1.5 to 2 percent paving grade asphalt. The low asphalt content bonds the open graded material into a stable mass without reducing permeability.

Asphalt treated permeable material has a drainage capacity up to 100 times greater than a California standard Class 2 permeable material. One installation after six winter seasons had an efficiency 12 times greater than a single layer system under the same service conditions.

The two layer system is no more difficult to construct than normal permeable blankets and normal construction equipment and methods can be used.

Direct cost comparisons indicate that two layer drainage systems can be constructed at a cost competitive with or lower than conventional single layer drainage systems.

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RONALD REAGAN, Governor

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DIVISION OF HIGHWAYS
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June 1974

Translab No. 632618
FHWA No. D-2-1

Mr. R. J. Datel
State Highways Engineer

Dear Sir:

Submitted herewith is a final research report titled:

PERFORMANCE
OF
TWO LAYER ASPHALT STABILIZED
DRAINAGE BLANKETS
FOR
HIGHWAY SUBDRAINAGE

By

Joseph B. Hannon, P.E. and Wesley C. Gray, C.E.T.
Co-Investigators

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Very truly yours,

JOHN L. BEATON
Chief Engineer, Transportation Laboratory

ACKNOWLEDGEMENTS

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The authors are especially indebted to Travis Smith, Principal Highway Engineer, the former chief of the Foundation Section, and to Donald L. Durr, Senior Materials and Research Engineer, for their supervision and past association with this study.

The Foundation Section of the California Transportation Laboratory conducted this study in cooperation with the Federal Highway Administration, U. S. Department of Transportation, as Item D-2-1 of Work Program HPR-PR-1(6). The contents of this report reflect the views of the Transportation Laboratory which are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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INTRODUCTION

Premature failure of a highway pavement can frequently be traced directly to excess water in the basement soil or in various elements of the structural section. Even when pavement failure is attributable to some other cause, excessive moisture is usually a contributory factor. Excess moisture changes the mechanical properties of the various materials and reduces the pavements ability to withstand repetitive vehicular loadings. The primary consideration is keeping the structural section as dry as possible. A water tight seal would probably be the most positive solution but a satisfactory seal cannot be achieved with existing technology. It is therefore of paramount importance to provide sufficient drainage to remove excess water before it can saturate the structural section.

Drainage of surface and subsurface water from the highway structural section has been a major consideration of road builders since the days of the Roman Empire. Modern highway drainage practice, pioneered by the famous British roadbuilder MacAdam (Circa 1820), has generally depended on a single layer system presumably for ease of construction and minimal cost. Highway drainage practice was and often still is the result of engineering judgment based on experience. The California Department of Transportation, in common with many other highway agencies, has in the past attempted to solve its drainage problems with a single layer drainage system. Historically the trends in California specifications for permeable materials have ranged from very coarse open graded material which had high drainage capacity but tended to plug readily to relatively fine well graded material which did not plug but had minimal drainage capacity. The current specification is a gradation that is basically an undersanded concrete aggregate and is probably as good a compromise between capacity and infiltration protection as any single permeable material.

Experience has convincingly demonstrated that a coarse open graded aggregate will have high capacity with a great potential to be plugged by infiltration while a fine well graded aggregate will resist infiltration but have low capacity. It follows that a multiple layer system can achieve both high capacity and infiltration resistance.

Seven, highly efficient, two layer drainage systems have been constructed in California. This report evaluates the performance of these installations and presents procedures necessary for design of an efficient system.

CONCLUSIONS

1. The two layer system can be placed successfully using normal construction procedures.

2. Rutting and displacement of the filter layer can present minor problems during placement of the asphalt treated permeable material.

3. An increase in fine material, the addition of water and some compactive effort could improve the stability of the filter layer providing that filter criteria are still met.

4. Traffic compaction can densify an uncompacted fine grained permeable material and result in a reduction in system capacity. This effect is most pronounced in single layer systems.

5. The use of 1.5 to 2 percent paving grade asphalt stabilizes the drainage layer and eliminates the problem of excessive displacement during placement of overlying elements of the structural section.

6. Rolling of the drainage layer will result in little, if any, densification but will not be detrimental unless aggregate particles are fractured.

7. Rolling may be impossible until the mix has cooled appreciably.

8. Asphalt treated permeable material has laboratory permeabilities ranging from 7,500 to 10,000 feet per day. This compares to perhaps 100 to 200 feet per day for class 2 permeable material. A two layer system using such a highly permeable material in the drainage layer will have the capacity to drain large quantities of subsurface water.

9. If properly designed, two layer installations can provide highly efficient drainage with no significant infiltration over an extended period.

10. The filter layer need only be as permeable as the native soil it is to drain. In many cases a relatively economical filter material such as aggregate base can be used. However, the designer must be certain that all filter criteria are met.

11. Two layer drainage systems can be constructed at a cost equal to or less than conventional single layer systems.

RECOMMENDATIONS

At the beginning of this study it was anticipated that higher cost would limit the use of two layer drainage systems to areas requiring special high capacity drainage. Since the direct cost appears to be favorable, consideration should be given to its use as a standard with single layer systems limited to special applications. The two layer system should be utilized as much as possible in wet subgrade areas since the benefits received in reduced pavement maintenance would more than balance any additional installation costs.

IMPLEMENTATION

Implementation has been more rapid than originally anticipated. In addition to the installations at Kneeland Road, 01-Hum-299 and 02-Sis-5, the key projects associated with this research study, four other two layer drainage systems were installed by contract change order on going construction projects. In addition to the seven completed projects discussed in this report, several proposed installations are presently in various stages of design.

"An Implementation Package for a Drainage Blanket in Highway Pavement Systems" was prepared by the Federal Highway Administration in May 1972 (13). To a large extent the content of that Implementation Package was based on information obtained during this study.

In February 1973 the Federal Highway Administration published a report prepared by Cedergren, Arman and O'Brien (12) for the development of guidelines for highway subdrainage. Their report is based on interviews and field investigations conducted in a number of states throughout the nation, including California, and contains criteria for design and construction of two layer drainage systems.

In a further effort to promote rapid implementation, the FHWA sponsored a seminar "Water in Pavement Workshop" in Seattle, Washington on November 20, 1973 and elsewhere in the United States on other dates.

The Materials Manual (14) of the California Department of Transportation Volume VI Section 7, also contains the filter criteria formulas and outlines their application for proper design of a two layer drainage system.

The theory of two layer drainage systems and the application of the design criteria was presented to three groups of district materials, bridge geology and Federal Highway Administration personnel as part of a week long seminar conducted by the California Department of Transportation Laboratory in 1973.

BACKGROUND INFORMATION

After observing the results of inadequate subsurface drainage in the wet cuts common to northwestern California Mr. W. R. Lovering, then District Materials Engineer for the California Division of Highways in Eureka, became an advocate of two layer drainage systems as a practical way to improve highway subdrainage. In 1960 he presented specific proposals for the use of two layer highway subdrainage systems (6). Criticism of the concept was based upon anticipated increased cost and additional construction problems in the placement of subsequent layers of the highway structural section over the unstable working table presented by the one sized aggregate necessary for the drainage layer. In 1962 Lovering and Cedergren (8) proposed the use of asphalt, in a lean mix, to stabilize the coarse aggregate in the drainage layer.

In 1967 Humboldt County constructed the first two layer drainage blanket in which asphalt was used to stabilize the open graded drainage layer. That project, on Kneeland Road, was the direct result of Mr. Lovering's continuing effort to demonstrate the practicability of the two layer concept. The results were reported by Cedergren and Lovering in 1968 (10).

In 1968 the California Division of Highways constructed a two layer drainage system on Road 01-Hum-299. This installation was evaluated during the initial phase of this research project and the results were presented in Highway Research Record No. 310 (11).

Following the successful installations at Kneeland Road and 01-Hum-299, a two layer drainage blanket was incorporated in the design of a proposed freeway on Road 02-Sis-5. At the time, it was anticipated that this would be the second project constructed on a state highway and the first to be constructed by contract. However, the report of the successful installation on Route 299 touched a responsive chord among highway engineers throughout the state. Before the two layer drainage system was completed on the 02-Sis-5 job four other two layer systems had been constructed by contract change order at diverse points around the state and a number of installations were in various stages of design. The seven installations constructed are located in geographical areas ranging from the environs of Los Angeles to near the Oregon border and from the central Sierra Nevada Mountains to the Pacific Coastal Ranges. To illustrate relative climatic conditions rainfall data is shown in Table 1 for each of the projects, beginning with the year the project was constructed. All seven projects are briefly discussed in chronological order in a later section of this report.

THEORY OF SYSTEM OPERATION

A drainage blanket placed beneath the base layers of a highway pavement is a direct way to remove subsurface water before it can saturate the overlying layers of the structural section. To be effective the permeable material in the blanket must transport all of the water which enters the blanket to a pipe or other outlet. The drainage blanket is not effective if water rises vertically through the blanket and saturates the overlying materials.

Even apparently minor seepage can produce a cumulative volume of water of surprising quantity. The collected water must be transported an appreciable distance from the crown or high side of the road to the underdrain on the low side. Often the water will travel an even greater distance, frequently several hundred feet, longitudinally down the grade. Drainage literature abounds with model illustrations showing the relatively low capacity of common sand and blended sand-gravel filter materials. For the purpose of this report it will suffice to say it has been shown that even a dripping faucet can exceed the capacity of a drainage blanket on a lineal foot basis.

The permeability of sand or blended sand-gravel materials, such as California's Class 2 permeable material, is very sensitive to minor changes in grading. Properly graded, this material may have a permeability of 100 to 200 feet per day or more. A change of grading in the finer sizes of only a few percent can reduce the permeability to 10 feet per day. Careful construction practice can minimize segregation but it is not reasonable to expect that this type of material can be placed without segregation. Because the grading is so critical, even minimal segregation can result in zones of greatly reduced permeability. These zones act as dams across the drainage channel with the result that the impounded water rises and saturates the overlying base material.

Clean coarse rock has the capacity to transport large quantities of water considerable distances. Unfortunately, water borne soil particles will be deposited in the voids between the coarse particles. The voids will eventually be completely filled and the material will then be useless as a drainage layer.

So we have two materials each exhibiting desirable qualities, but also undesirable ones. Coarse rock has capacity but is prone to infiltration and plugging. Fine grained well graded filter material resists infiltration but lacks capacity. By combining the two materials in a dual system the desirable properties of each can be utilized. A relatively coarse open graded aggregate supplies capacity and is protected from infiltration by a properly graded filtration layer. The capacity of the well graded sand or blended sand-gravel used in the filtration layer is no longer a concern. When water moves vertically through the filtration layer it enters the high capacity drainage layer and is removed before it reaches the overlying base material.

DESIGN CRITERIA

The Terzaghi filter criteria, presented by Bertram in 1940, was the first rational approach to the solution of the filtration problem. Modified by others (2),(3),(4),(5),(7),(9) the design criteria have been developed to a high degree as evidenced in earth dam construction where up to five layers are used to provide drainage capacity without infiltration.

It cannot be overemphasized that the various elements of the system must each be compatible with their adjacent elements or infiltration will eventually plug the system and render it inoperable. The two layer system in basic form consists of a filtration layer and a drainage layer but the designer must also always consider the adjacent layers. Hence the design concept must encompass at least four layers. These are the basement soil, the filtration layer, the drainage layer and the overlying base or subbase. Each of these four must meet established filter criteria when compared to adjacent layers to assure that the system will function effectively throughout its design life. The basic filter criteria formulas and a brief description of their application is given in Table 2. The reader should also consult one or more of the last three publications (12),(13), (14) listed in the reference section of this report for more detailed information.

The open graded drainage material is basically a 3/4" x No. 4 mineral aggregate specified in a manner to prevent the material from being all 3/4" or all No. 4. The recommended specification limits are shown in Table 3. This recommended grading has sufficiently high capacity for most highway applications and is compatible with filtration layers constructed with many permeable and base materials commonly used in California. Specification limits for California's Class 2 permeable material and Class 2 aggregate base are also shown in Table 3.

Aggregate base is mentioned because, while the filtration layer must meet primary filter criteria it need be no more permeable, or in practical application only slightly more permeable, than the native soil to be drained. By taking advantage of this concept a considerably less expensive product can often be used for the filtration layer. Standardized grading specifications for the various layers could circumvent repetitious filter criteria comparisons, but such an approach would often result in the use of a premium priced product where a more economical material would serve just as well.

PROJECTS CONSTRUCTED

Kneeland Road

The first two layer asphalt treated drainage system was constructed in California by Humboldt County in 1967. The installation was located on Kneeland Road near Eureka in the north coastal area. While the amount of factual data collected was minimal it was demonstrated that the drainage system elements could be placed with a paving machine. This project was discussed in Highway Research Record No. 310 (11). Field permeability testing and evaluation for possible infiltration, was performed in 1973 and is discussed in a later section of this report.

01-Hum-299

The second two layer installation in California and the first on the state highway system was constructed by the California Division of Highways on Route 299 between Arcata and Willow Creek in the same general geographic area as Kneeland Road. The installation was constructed in 1968 but adjacent portions of the road were not completed until later. The road was opened to traffic in 1972. The report in Highway Research Record No. 310 (11) discussed this installation in detail. A brief description is given below.

The site consisted of a 600 foot long wet cut in a high rainfall area which was divided into two subsections. In one 400 foot subsection a two layer drainage blanket was constructed consisting of 0.3 foot of standard Class 2 permeable material for filtration and 0.4 foot of asphalt treated open graded permeable material for drainage. The adjacent 200 foot subsection was designed as a single layer control section containing 0.7 foot of Class 2 permeable material. The experimental section was built with no undue construction problems and field permeability measurements indicated the two layer subsection had a capacity from 3 to 9 times greater than the single layer control section.

Core samples were obtained in the spring of 1969. The moisture content of the various elements of the structural section were of particular interest especially in the previously mapped natural spring areas. Moisture samples did not show a significant variation and nothing approaching a saturated condition was found.

Grading of individual samples obtained during and after construction were presented in the interim report. An average grading curve for the native soil, filtration layer, drainage layer and overlying base are shown on Figure 1. These test sections were also reevaluated in the Spring of 1973 to observe the influence of several winter seasons and the effects of traffic as discussed in detail later in this report.

03-Sut-99

In the spring of 1970 excavation of a depressed section on the multilane Route 99 freeway in Yuba City was essentially complete when groundwater was encountered in a trench being dug for a pipe at the low point of the depressed section near Queens Avenue. Groundwater in the area had been monitored for several years prior to construction and had consistently been a minimum of 10 feet below subgrade elevation. Water in the pipe trench, and a check of observation wells, showed the water table had risen about 8 feet above previous norms and was then about 2 feet below subgrade elevation. The dramatic rise in the water table was attributed to the City of Yuba City shutting down their water well pumping system with the opening of their new filtration plant. Based on the possibility that the water table would rise still higher and saturate the subgrade, longitudinal underdrains and a permeable blanket were installed for a distance of 1,000 feet under both the left and right roadways. Native soil beneath the permeable blanket was sandy in nature and met the requirements for a filter material. Consequently, a separate filter layer was not needed at this location.

The asphalt treated permeable material was delivered to the project in bottom dump trucks and placed on the grade in a windrow. The Vee trench underdrains were filled by blading the material into the trench from an adjacent windrow. The 0.35 foot thick permeable blanket across the roadway was brought to grade with a motor grader spreading the windrowed material. Final grade and finish was achieved by a wheeled tractor fitted with a hydraulically controlled drag. The finished appearance was excellent.

No effort was made to compact the asphalt treated permeable material. Densities were obtained with a nuclear device and indicate that little or no densification can be accomplished by rolling. Densities in the vicinity of the underdrain trenches, where there could not have been any compactive effect, ranged from 90 to 99 pounds per cubic foot and averaged 95 pounds per cubic foot. The wheels of a loaded bottom dump truck passing slowly over the 0.35 foot of asphalt treated permeable material spread on the roadway exert an appreciable compactive force. Densities taken in these wheel tracks averaged 96 pounds per cubic foot or an increase in average densification of only one pound.

07-LA-210

A large quantity of groundwater was encountered during the construction of a large through cut on the Route 210 portion of a complex, multi-route interchange located in eastern Los Angeles

County near the City of Pomona. Groundwater had been observed since the early stages of excavation and had persisted over the ensuing months. When excavation in the cut was completed early in 1971 seepage areas and dug pits containing standing groundwater were evident over a major portion of the subgrade area. Appreciable quantities of flowing groundwater were also observed. It was obvious that subsurface drainage would be required either in the form of an extensive system of herringbone underdrains or with a permeable blanket. Considering the extensive area requiring treatment, 1,500 feet of multilane divided freeway plus a portion of a connector road, a permeable blanket appeared to be the most reasonable solution.

A two layer drainage system was selected primarily because of the high drainage capacity provided. The thinner drainage section could also be accommodated in the planned structural section without increasing its overall thickness which would have required additional excavation. The section as constructed consisted of 0.25 foot of aggregate base as the filtration layer, 0.35 foot of asphalt treated permeable material overlaid by a minimum of 0.25 foot of aggregate base. The elements of the drainage system were placed without incident using a paving machine and normal construction procedures.

05-SBt-101

About 18 miles north of Salinas, Route 101 crosses the main trace of the San Andreas Fault in the Coast Range Mountains near San Juan Bautista. Construction of Route 101 to full freeway standards required a major through cut across the fault zone and it was recognized that the highly altered and fractured fault material would present major stability and subdrainage problems. The original design included underdrains for a distance of 1,200 feet along both the right and left sides of this multilane divided facility as well as a one foot thick blanket of permeable material beneath the structural section.

Following excavation in the fall of 1971 it was apparent that the groundwater problem was considerably more severe than had been originally anticipated but was confined to an area about 600 feet in length. The longitudinal underdrains were supplemented with lateral underdrains and the single layer drainage blanket was replaced with a high capacity two layer system.

The two layer drainage blanket consisted of 0.35 foot of Class 2 permeable material in the filtration layer and 0.35 foot of asphalt treated permeable material in the drainage layer.

03-Pla-49

In the fall of 1972 a drainage problem became evident during the widening of Route 49 near Auburn in the foothills of the central Sierra Nevada Mountains. Widening the existing two lane road to a four lane all paved section on the same general grade and alignment entailed excavating a short distance into a series of low cuts on the left and constructing additional fill on the right. Underdrains had been installed under the left shoulder of the original two lane road. No provision had been made for additional subdrainage in the widened area between the underdrains and the new toe of cut and seepage quickly saturated the grading plane in this area.

Asphalt treated permeable material, without a filtration layer, was placed in a trench excavated one foot below the grading plane and as a four foot wide blanket placed in lieu of base under the shoulder. The permeable material was installed in six sections individually ranging in length from 300 to 800 feet and in combination totaling 3,100 feet. In effect the system was designed as a "French Drain" with no conduit except for an outlet pipe at the downhill end of each section. One side of the blanket did extend to a contact with the exposed permeable material in the original underdrains. The performance of this system was evaluated in the spring of 1973 and again in the spring of 1974. The results of this evaluation are given in the "Performance Evaluation" section of this report.

02-Sis-5

In 1969 it came to our attention that a district materials engineer had recommended an extensive permeable blanket in a wet cut on Interstate Route 5 near Weed in northern California. The project was already in an advanced stage of design but through the willing cooperation of several design engineers a thinner two layer drainage blanket was substituted. Consequently this was the first two layer drainage system installed as a bid item on a major construction project.

The drainage system was installed under both the northbound and southbound roadways of this multilane freeway for a length of 2,600 feet. The drainage elements were placed in the fall of 1972 but the overlaying base and pavement was not placed until late spring 1973. As a consequence the open graded drainage layer was left open to the elements during the winter months. Rain washed slough from the cut slopes caused minor contamination in localized areas but in general the drainage system suffered little overall damage.

The drainage section consisted of 0.5 foot of Class 2 permeable material in the filtration layer and 0.5 foot of asphalt treated permeable material in the drainage layer overlaid by plant mixed cement treated base. The filtration and drainage layers were considerably thicker than the 0.30 to 0.35 foot thickness generally recommended. At the time this project was designed the only previously constructed two layer drainage systems were on Kneeland Road and Route 299. Both of these projects had been carefully constructed by day labor. The extra thickness used at Weed was an intentional overdesign to ensure an effective system in the event unforeseen problems should develop during construction. Experience gained with construction of the four intervening projects and the ease of construction on this project ultimately proved that the extra thickness was not necessary.

In all other projects discussed in this report the asphalt treated permeable material was a hard mineral aggregate and the optimum asphalt content, using 85-100 paving grade asphalt, had always ranged from 1.5 to 1.8 percent. On this project, the permeable material was a porous, all crushed volcanic material. The specifications had been set up with a maximum requirement of 3% asphalt based on previous experience with dense rock. The full 3% was used but many of the rock particles were not fully coated with asphalt. Some raveling and rocks flying from the wheels of passing construction vehicles indicated the drainage layer was not firmly cemented. However, the layer was stable enough to provide a good working table and the cement treated base was placed without difficulty. The harshness of the all crushed product probably enhanced the stability. It is interesting to note that this aggregate required over eight percent asphalt to produce a normal dense graded asphalt concrete.

One core sample was obtained after PCC paving had been completed. This boring was located in the center of the number 1 southbound lane at Station 970+00. The primary purpose of this boring was to determine if cement treated base, placed directly on the open graded drainage layer, had penetrated into the drainage material. A well defined plane existed between the cement treated base and the asphalt treated permeable material. Removal of the top 0.1 foot of asphalt treated permeable material revealed tightly bonded material with no visible cement treated base penetration.

Average grading curves for the native soil, the filtration layer, and the drainage layer are shown on Figure 2. Results of the permeability testing is discussed later in this report.

PERMEABILITY TESTING

Laboratory Testing

Testing for permeability of filtration layer material conformed to Test Method No. Calif. 220-B. A schematic diagram of the apparatus is shown in Figure 3.

Class 2 permeable material was used in the filtration layer at 41-Hum-299 and at 02-Sis-5. At field density the material used at 01-Hum-299 had a permeability of about 200 feet per day while the material used at 02-Sis-5 had a permeability of about 100 feet per day. Aggregate base was used for the filtration layer at Kneeland Road and contained a much higher percentage of fine sizes. As would be expected the permeability was much lower, less than 10 feet per day.

The open graded asphalt treated material used in the drainage layer is so highly permeable that problems developed in attempting to measure the permeability using normal test equipment and procedures. Constant head tests were initially attempted with little success. Later, a falling head test was improvised which gave better results.

Asphalt treated material from Kneeland Road was heated in the laboratory and remolded to facilitate placement in the permeameter molds. The normal water supply was temporarily supplemented and tests were run using an extremely low head. The results of these tests were not considered reliable due to problems in fabricating the specimens and potential inaccuracies at low head. However, later testing indicated the results may not have been as erroneous as originally believed.

A different approach to sample preparation was used when the 01-Hum-299 project was built. Three chunks of in-place material were obtained after construction. The intent was to trim the specimens to fit the permeameter mold. However, even the most careful trimming resulted in a sample of very irregular shape. One sample disintegrated during handling. The two remaining samples were placed in permeameter molds after trimming, and the periphery of the sample inside the mold was sealed with plaster of paris. Although tests were run, their accuracy is questionable because the effective area of the samples could not be precisely determined.

The problem of sample fabrication was finally solved by taking the permeameter molds to the job site and filling them with hot asphalt treated permeable material as the material was delivered on the job. Samples with three different densities were successfully fabricated in this manner at 03-Sut-99 and again at

02-Sis-5. However, a further problem developed when sufficient water flow was not available in the laboratory to develop a constant head. This problem was solved by attaching a lucite cylinder to the top of the permeameter mold and conducting a falling head test. Photograph 1 shows the modified equipment during a test. The number 16 screen normally used to retain the sample was removed for this test when it was found to impede the free flow of water through this highly permeable material. The asphalt in the specimen supplied sufficient bond to hold the specimen in the permeameter.

Water for the test was supplied by a 2-inch line. The lucite cylinder was filled to the top and then the water was allowed to fall a few inches, to help reduce turbulence, prior to timing. The time required for the water column to fall a distance of 8 inches was then recorded. Turbulence and air content of the water column were appreciable throughout the test. However, individual test results were generally repeatable and permeabilities of the materials from the two projects are comparable. The numerical value of permeability would probably be increased using de-aired water and under conditions of laminar flow. However, the expense of fabricating equipment to more precisely measure the permeability of this material could not be justified. From a practical standpoint the testing demonstrates the material has a much greater capacity than required for any normal application. The results of all the laboratory permeability tests are shown in Table 4.

Field Testing

To measure the relative field drainage capacities of the subdrain systems, a constant head permeability apparatus having a high capacity was designed and fabricated. A schematic diagram of the device and its installation is shown on Figure 4. Photograph 2 shows it in use at an actual test installation.

The apparatus consists of an inner and outer cylinder differing in radius by 0.3 feet. When used to measure the capacity of the two layer system the inner cylinder projects into the filtration layer approximately one inch. The outer cylinder is placed directly on top of the filtration layer. The area between the two cylinders is sealed with bentonite clay or heavy grease. This arrangement forces the water, introduced through the inner cylinder, to travel a minimum of 0.3 foot through the filtration layer material before reaching the open graded drainage layer. If this distance is the same as the thickness of the filtration layer then system capacity as measured by the device is, within reason, directly comparable to the systems capacity to handle subsurface water. The 0.3 foot spacing was originally selected to match the 0.3 foot thickness of the filter layer used at 01-Hum-299. The same spacing was retained for field permeability testing at the other projects and all measurements are directly comparable. In addition to measuring overall system capacity, the capacity of the open graded drainage layer can also be measured by placing the device directly on top of the open graded material. The capacity of the single layer control section on the 01-Hum-299 project was measured by inserting only the inner cylinder to the approximate midpoint of the permeable layer.

The test consists of introducing water under a constant head until a steady state flow condition is reached. Then the quantity of water introduced into the system per unit of time is measured. The results of all field permeability testing is shown in Table 5 and the significance of the results are discussed in the following section of this report.

PERFORMANCE EVALUATION

A total of seven two layer drainage blankets have been constructed in California. As a concluding phase of this study the two oldest projects, Kneeland Road constructed in 1967 and 01-Hum-299 constructed in 1968, were evaluated in the spring of 1973 to determine if their efficiency has been impaired with time and traffic.

The installation on 01-Hum-299 was constructed in the fall of 1968 although the road was not opened to traffic until 1972. Initial field permeability tests were made in 1969 and the same testing sequence was repeated in 1973. The comparative data from these tests are shown on Table 5. The 1973 tests were conducted a few feet from the 1969 test sites to represent the initial condition as closely as possible.

The 1973 test series indicates the average permeability of the asphalt treated permeable material is slightly higher than the permeability measured in 1969. No rational explanation can be offered for this. However, the 1969 data, while averaging slightly lower, does fall within the extremes measured in 1973. Permeabilities measured at two other locations are also of the same general magnitude. All are considered to be valid data.

The control section at 01-Hum-299 was a normal single layer blanket of Class 2 permeable material and permeability was much lower in 1973 than in 1969. This is logical for the material was not compacted during construction and had not been subjected to traffic loading when the 1969 data was collected. The road was opened to traffic in 1972 and the material had therefore been compacted to some degree by the time the permeability was measured in 1973. Whether the material had reached its ultimate density in 1973 is not known. Drainage capacity of the control section averaged 2.8 gallons per minute in 1969 and only 0.48 gallons per minute in 1973. If the one abnormally high value obtained in 1969 is thrown out then the average capacity in 1969 is reduced to 0.96 gallons per minute, still twice the 1973 average.

In 1973 the two layer system was also found to have a reduced capacity. Again this is a result of traffic compaction since the filtration layer was constructed without compaction using the same Class 2 permeable material as the control section. Disregarding inconsistencies in data, the capacity of the two layer system averaged 9.0 gallons per minute in 1969 and 5.7 gallons per minute in 1973.

Most informative, however, is a comparison of the two layer data to the control section data. In 1969 the two layer system was 3.2 times as efficient if all of the values obtained in the control section are used. If one high reading is discarded from the data the two layer system becomes 9.4 times as efficient. Based on data collected in 1973 the efficiency of the two layer system increased to 11.9 times that of the control section. This increase is significant because the prime cause was reduced efficiency of the single layer drainage blanket, a dramatic illustration of why permeable blankets sometimes fail to perform in a satisfactory manner.

The permeability of the asphalt treated permeable material installed at Kneeland Road was also measured in the spring of 1973. These results are shown in Table 5, but are of limited value because no prior data exists for comparison. However, the permeability is in the same general range as the other projects tested.

Material excavated during the installation of the field permeameters was carefully inspected for signs of possible infiltration. At one site at 01-Hum-299 minor infiltration from the overlying layer was observed. Except for this one site no signs of infiltration were observed in any of the other excavations at 01-Hum-299 and none were observed at Kneeland Road. At the time of the 1973 evaluation, the drainage facility at Kneeland Road had been in service through seven winter seasons and the 01-Hum-299 installation had been subjected to six. The good condition of these two systems after this length of service and their continuing efficiency as measured by field permeability tests clearly indicates that a properly designed two layer drainage system can provide high capacity drainage for many years.

As previously stated the installation on Road 03-Pla-49 was constructed in the fall of 1972 as a "French Drain". A conduit was not installed and a filtration layer was not used to protect the open graded drainage layer. Further, established filter criteria was not used to design the installation. Grading curves of the native soil were not readily available and the design was based on the visual evaluation of the various materials involved. In the spring of 1973, after the drainage system had been in operation for one winter, four cores were taken through the pavement to evaluate the performance of the system. In two of the borings the full 0.3 foot of asphalt treated permeable material was found in place as anticipated. Groundwater was being removed in a satisfactory manner and no signs of infiltration were observed. No asphalt treated permeable material was found in the third boring and only scattered fragments of the material were found in the last boring. In these borings water was flowing in the lower portion of the aggregate base near the contact with the grading plane. In the spring of 1974 six more cores were taken through the pavement. The full thickness of asphalt treated permeable material was found at all six locations. The permeable material was carrying an appreciable quantity of water, estimated in excess of 25,000 gallons per day. Dye was introduced in one boring and appeared at the system outlet 25 feet away in 2 minutes. No other flow measurements were made.

Cores of the permeable material were inspected both in the field and in the laboratory. Some deleterious material was observed but in such minor quantity as to present no immediate concern for the system's performance. More than normal asphalt stripping was noted but this is not important because the asphalt serves only as a binder to aid construction and serves no further purpose. The stripping may be attributed, at least in part, to the large flow of water at relatively high velocity which probably carries a fairly heavy bedload of abrasive sand grains. This heavy flow is probably beneficial in that it tends to keep the system clean.

The accuracy of the original design was checked using filter criteria. Four samples of the native soil were obtained from the area immediately beneath the open graded permeable material. All four curves met the D85:D15 criteria but two of the curves failed to meet the D50:D50 criteria. This comparison indicates that while the design is borderline it is probably satisfactory. This evaluation is also supported by observed performance after two winter seasons of operation. However, there is an obvious moral here. Every drainage system using open graded material should be properly designed even when job pressure makes an immediate answer desirable. The tool for proper design, filter criteria, is available to the engineer and when properly applied will result in an efficient design.

COST OF CONSTRUCTION

Comparative cost data for the various elements of the six drainage systems installed on state highways are shown in Table 6. Analysis of the data presented in this table indicates the cost was initially higher but has tended to become lower as contractors became familiar with the product.

On the last four installations the cost of asphalt treated permeable material ranged from $5.35 to $7.07 per ton. The statewide cost of Class 2 permeable material for four years (1969-1972) averaged $3.55 per ton. From this it appears reasonable to assume that the price of asphalt treated permeable material will not be more than twice that of Class 2 permeable material. Since each element of the two layer system requires a thickness of only 0.3 to 0.35 foot, the cost of the two element blanket will be approximately equal to the cost of a single layer blanket using one foot of untreated permeable material and appreciably less than a thicker single layer blanket. The two layer system will often permit the use of a less expensive material, such as aggregate base, for the filter layer. This would result in an additional saving.

In addition to comparing favorably on a direct cost basis, the two layer system has a much higher drainage capacity. Certainly in terms of cost per unit of drainage capacity the two layer system is several times more economical.

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Figure 1

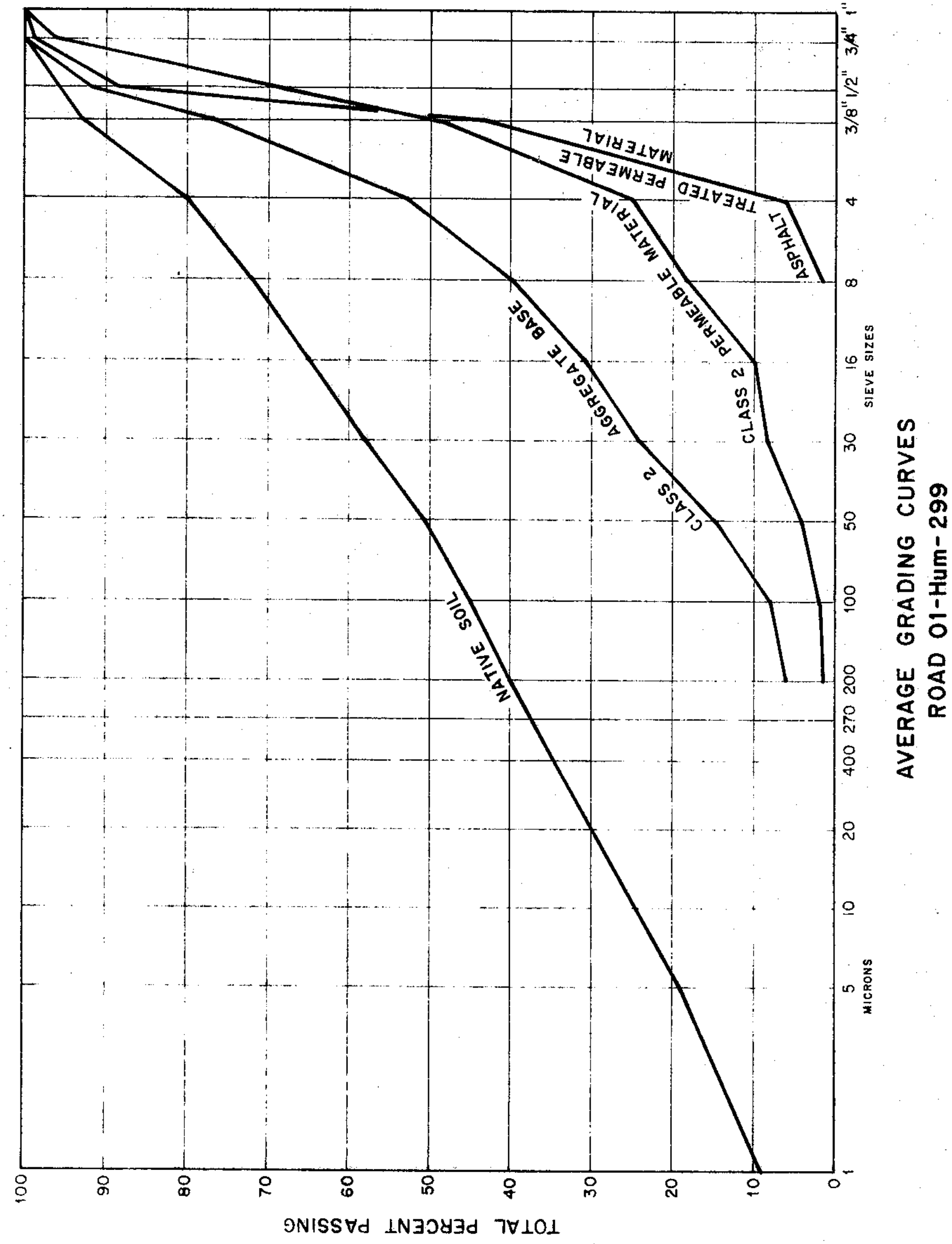
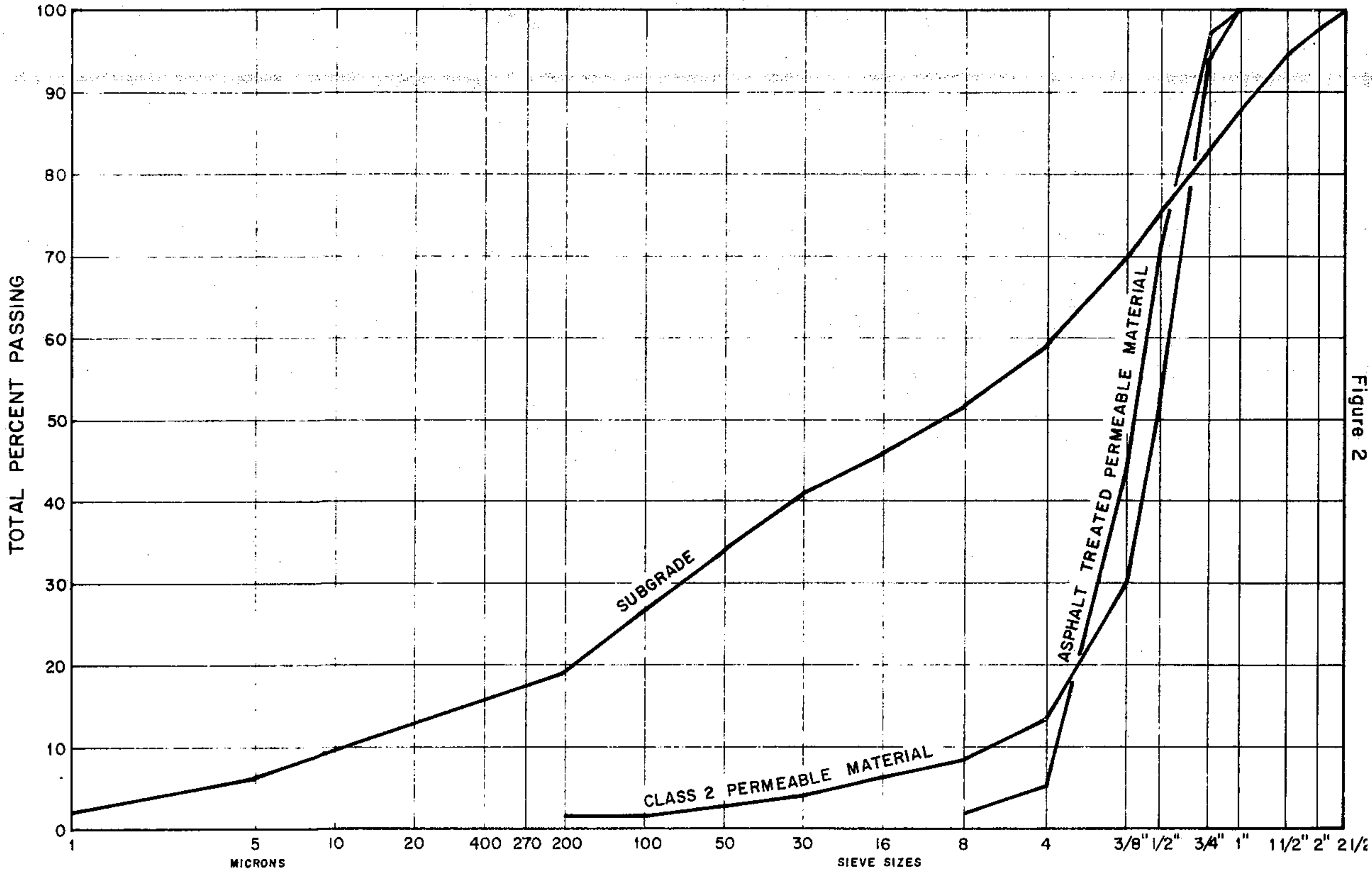
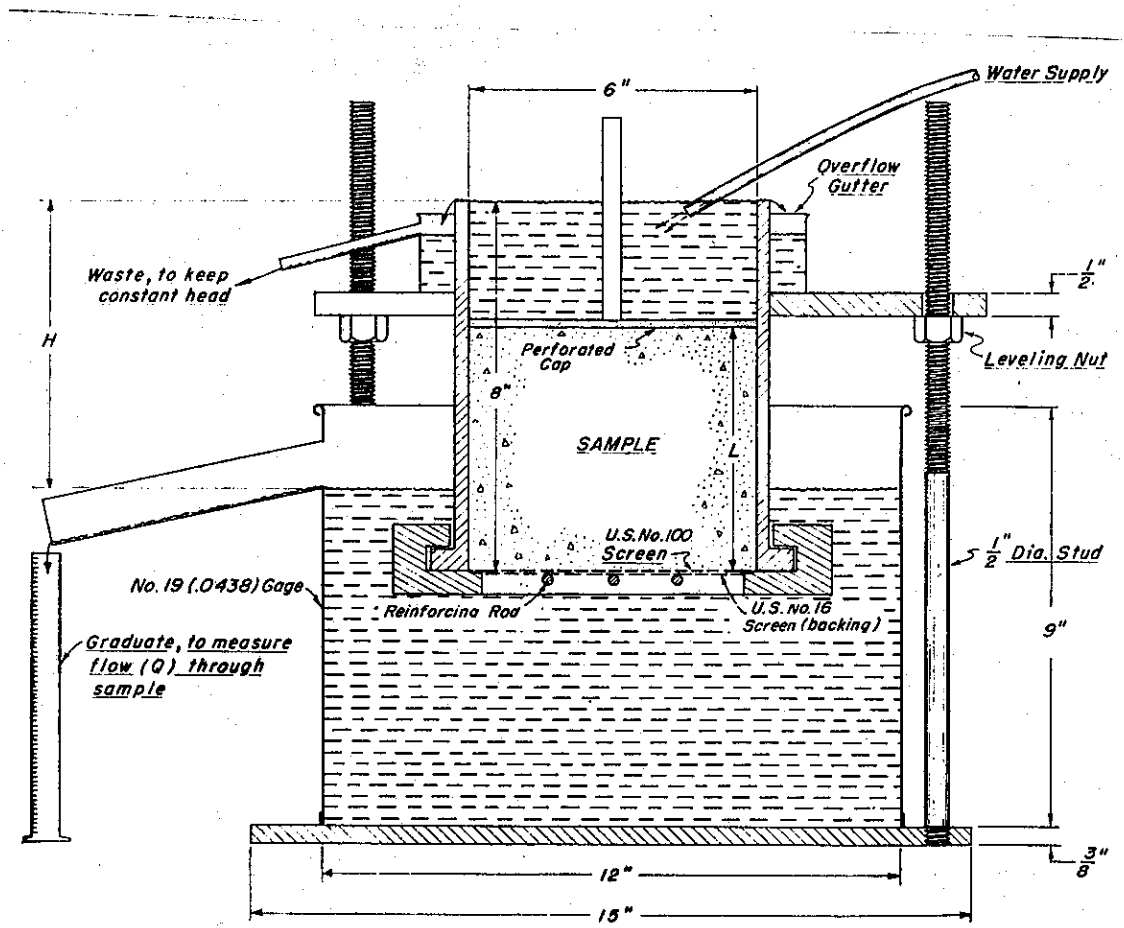

AVERAGE GRADING CURVES
ROAD 01-Hum-299
TOTAL PERCENT PASSING
100
90
80
70
60
50
40
30
20
10
0
SIEVE SIZES
MICRONS
1
5
10
20
400
270
200
100
50
30
16
8
4
3/8"
1/2"
3/4"
1"
NATIVE SOIL
AGGREGATE BASE
CLASS 2
PERMEABLE MATERIAL
CLASS 2
TREATED PERMEABLE MATERIAL
ASPHALT

Figure 2



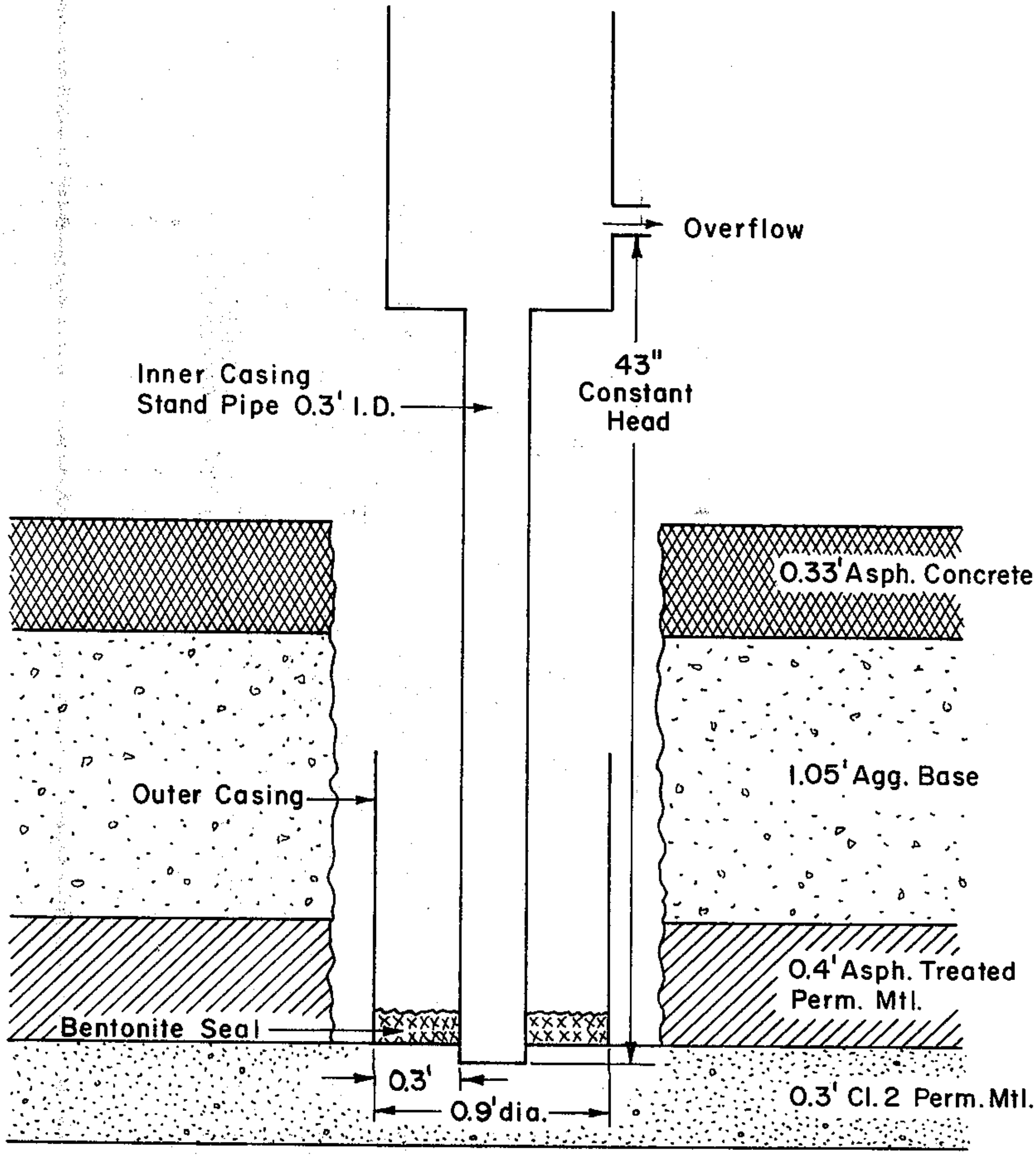
AVERAGE GRADING CURVES
ROAD 02-Sis - 5

Figure 3



SCHEMATIC DIAGRAM OF APPARATUS
FOR LABORATORY CONSTANT-HEAD PERMEABILITY

Figure 4



SCHEMATIC DIAGRAM OF APPARATUS
FOR CONSTANT HEAD FIELD PERMEABILITY TEST

No Scale

Table No. 1

RAINFALL DATA - Inches

	Annual Normal	(Winter Season - Oct-Feb - inclusive) 1967-68	1968-69	1969-70	1970-71	1971-72	1972-73	1973-74
Kneeland Road	64.0	27.8	67.5	54.0	60.0	49.0	38.8	-
01-Hum-299	59.4	-	47.3	37.0	43.0	42.6	-	56.0
03-Sut-99	20.0	-	-	-	14.1	9.9	19.9	19.6
07-LA-210	17.8	-	-	-	-	7.9	19.3	10.5
05-SBt-101	15.3	-	-	-	-	10.1	24.8	13.6
03-Pla-49	35.0	-	-	-	-	-	36.4	31.0
02-Sis-5	19.6	-	-	-	-	-	18.5	33.0

Table No. 2

Filter Criteria

To prevent infiltration and clogging

$$\frac{\text{15 percent size of coarse material}}{\text{85 percent size of fine material}} \leqq 5$$

$$\frac{\text{50 percent size of coarse material}}{\text{50 percent size of fine material}} \leqq 25$$

To assure adequate capacity

$$\frac{\text{15 percent size of coarse material}}{\text{15 percent size of fine material}} \geqq 5$$

To determine the 15-, 50- and 85-percent size of the four layers, representative grading curves are plotted in graphic form and the particle sizes at each percentage are read directly from the graph. Usually the percentage passing is plotted along the Y axis to arithmetic scale and the particle size is plotted on the X axis to a logarithmic scale.

Migration between adjacent layers is minimized when the gradation curves of the two layers are approximately parallel. Gradings of each of the four material layers must be evaluated. In progression each layer is compared to an adjacent layer making a total of three separate calculations for each comparison, all involving the three formulas presented above. In comparing the native soil to the filter layer the filter layer is the coarse material in the formula and the native soil is the fine material. In comparing the filter layer to the drainage layer, the filter layer becomes the fine material in the formula and the drainage layer is the coarse material. In the final comparison the drainage layer remains the coarse material and the base or subbase is the fine material.

Table No. 3

SPECIFICATION GRADING LIMITS

Sieve Sizes	Asphalt Treated Permeable Material	Class 2 Permeable Material	Class 2 Aggregate Base
1"	100	100	100
3/4"	90-100	90-100	87-100
3/8"	40-70	40-100	-
No. 4	0-10	25-40	30-60
No. 8	0-5	18-33	-
No. 30	-	5-15	5-35
No. 50	-	0-7	-
No. 200	-	0-3	0-12

Table No. 4

LABORATORY PERMEABILITY TESTS

		Filtration Layer		Drainage Layer	
	Dry Density lb/cu.ft.	Agg. Base Const.Hd.Perm. ft/day	Cl 2 PM Const.Hd.Perm. ft/day	ATPM Const.Hd.Perm. ft/day	ATPM Falling Hd.Perm. ft/day
Kneeland Road	130	8			
	134	3			
	140	1			
	101			8,700	
	108			7,400	
	111			4,500	
01-Hum-299	120		290		
	128		162		
	131		40		
	137		10		
	-			3,000*	
	-			21,900*	
03-Sut-99	101				10,700
	104				7,500
	110				7,000
02-Sis-5	96		305		
	101		81**		
	102		100**		
	-				10,400
	105				9,000
	106				8,400

*Sample Area Approximate.
**Sample degraded by test compaction.

Table No. 5

FIELD PERMEABILITY TESTS
CONSTANT HEAD - 43-INCHES
(Gal. per min.)

	Station	ATPM Sept. 1969	ATPM April 1973	Two-Layer System Sept. 1969	Two-Layer System April 1973	Control Section Sept. 1969	Control Section April 1973
Road 01-Hum-299 (East of Arcata)	485+65	-	30	7.2	3.6	-	-
	486+90	33	35	7.8	12.0	-	-
	487+90	32	40	16.2	3.0	-	-
	488+50	-	43	4.8	4.3	-	-
	489+40	-	-	-	-	1.02	0.45
	489+85	-	-	-	-	0.90	0.20
	490+50	-	-	-	-	6.60	0.80
Kneeland Road (FAS Project in Humboldt County)	1+26	-	40	-	-	-	-
	1+90	-	53	-	-	-	-
	2+62	-	50	-	-	-	-
Road 02-Sis-5 (Near Weed)	968+50	-	35	-	-	-	-
	969+00	-	44	-	-	-	-
	970+00	-	-	-	12	-	-
	971+00	-	-	-	11	-	-
	975+50	-	-	-	15	-	-
	978+50	-	42	-	-	-	-

Table No. 6

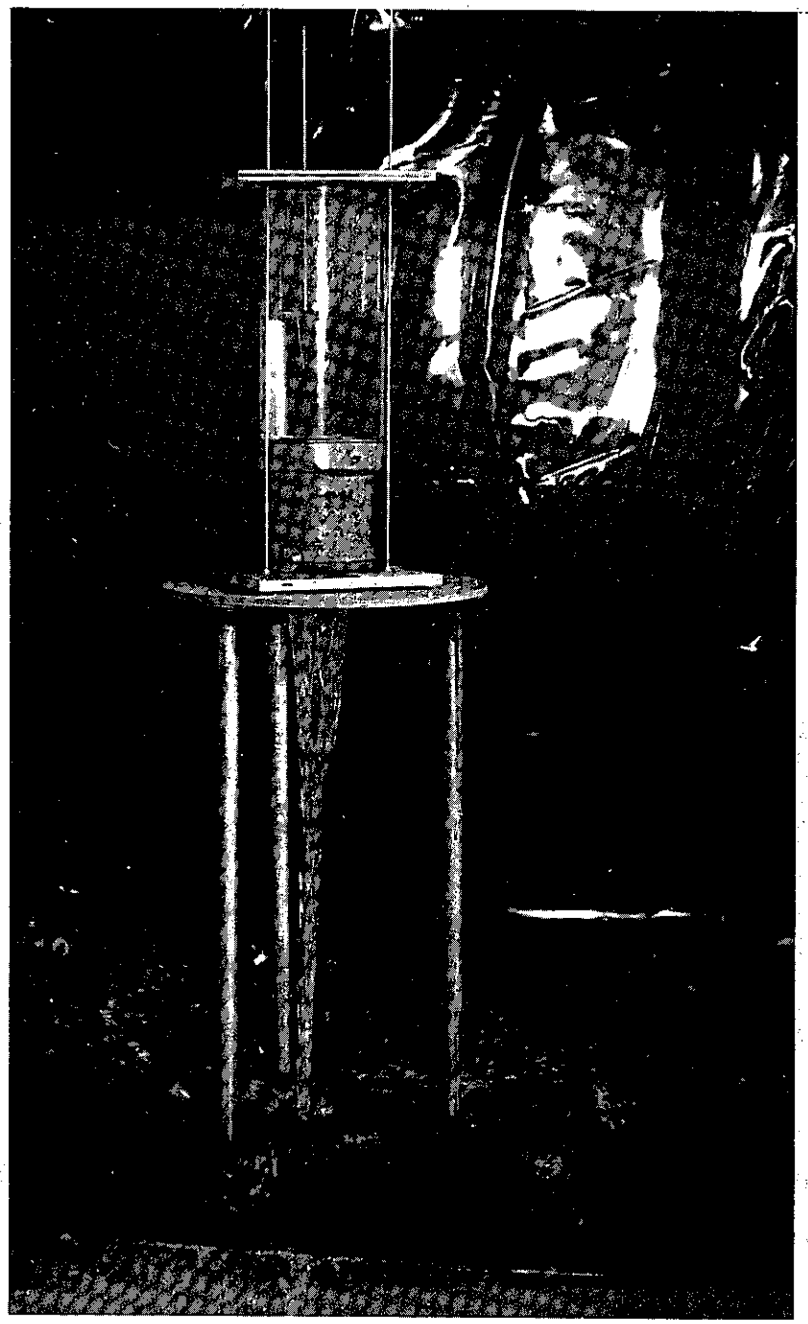
COST OF MATERIALS

	Cl 2 PM $/Ton	Cl AB $/Ton	ATPM $/Ton
01-Hum-299	3.60*	-	9.25*
03-Sut-99	-	-	8.24* 8.77**
07-LA-210	2.83*	1.80*	5.35*
05-SBt-101	8.00**	-	7.00**
03-Pla-49	3.30**	-	7.07*
02-Sis-5	3.00**	-	6.00**

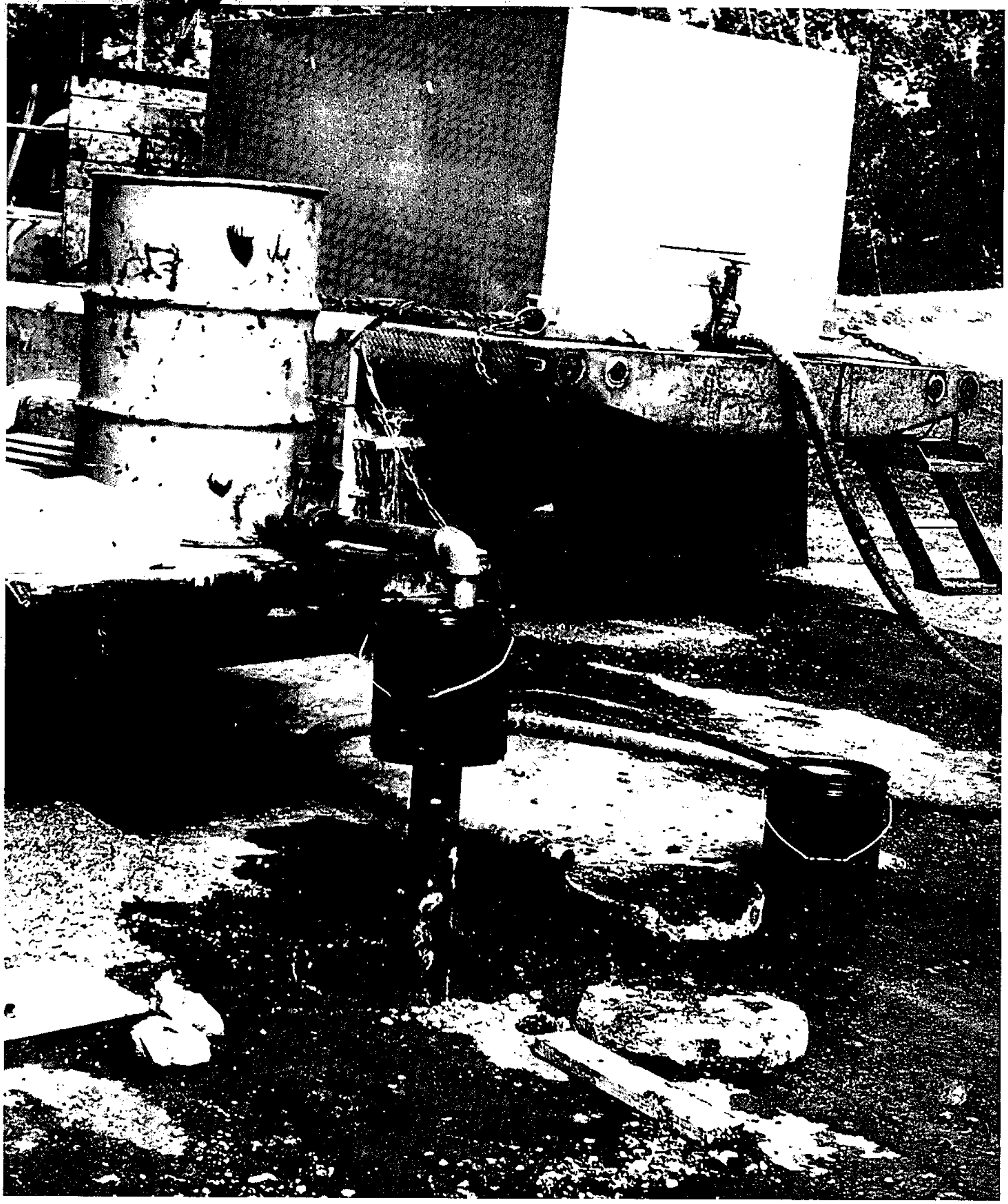
*Delivered to job but does not include placing.

**In place

PHOTOGRAPH NO 1



IMPROVISED FALLING HEAD
PERMEABILITY DEVICE DURING TEST



FIELD PERMEABILITY TEST

PHOTOGRAPH No. 2